Essay Two

Keeping Time

From before recorded history, people have used events in the heavens to mark the passage of time. The day, the month, and the year were all originally defined in terms of obvious astronomical phenomena. The day was the time interval from sunrise to sunrise. The month was the interval from new moon to new moon. The year was the time it takes for the Sun to complete one circle of the zodiac. Astronomical events are not perfect time markers, however: even the day and year need to be defined with care if we are to have reliable clocks and calendars. Otherwise, we may end up with snow in "summer" and heat waves in "winter."

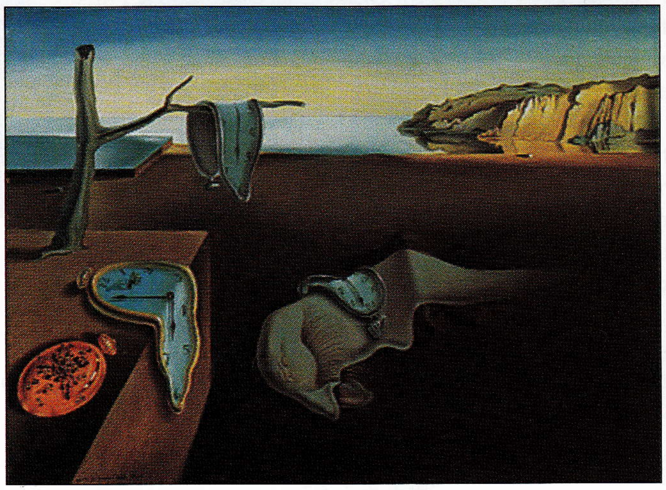
Length of the Daylight Hours

Although each day lasts 24 hours, the number of hours of daylight, or the amount of time the Sun is above the horizon, changes drastically throughout the year unless you are very close to the equator. For example, in northern middle latitudes, including most of the United States, southern Canada, and Europe, summer has about 15 hours of daylight and only 9 hours of night. In the winter, the reverse is true.

The change in number of hours of daylight as seasons change

This variation in the number of daylight hours is caused by the Earth's tilted rotation axis. Remember that as the Earth moves around the Sun, its rotation axis points in roughly a fixed direction. Thus, the Sun shines more directly on the Northern Hemisphere during its summer and less directly during its winter. The result (as you can see in fig. E2.1) is that only a small part of the Northern Hemisphere is unlit in the summer, but a large part is unlit in the winter. Thus, as the Earth's rotation carries us around, only a relatively few hours of a summer day are unlit, but a relatively large number of winter hours are dark. Figure E2.1 also shows that on the first day of spring and autumn (the equinoxes), the hemispheres are equally lit, so that day and night are of equal length everywhere on Earth.

If we change our perspective and look out from the Earth, we see that during the summer, the Sun's path is high in the sky, so that the Sun spends a larger portion of the day above the horizon. This gives us not only more heat but also more



Dalí, Salvador. *The Persistence of Memory* [*Persistence de la Mémoire*]. 1931. Oil on canvas, $9\frac{1}{2} \times 13$ inches (24.1 × 33.0 cm). The Museum of Modern Art, New York. Given anonymously.

hours of daylight. On the other hand, in winter the Sun's path across the sky is much shorter, giving us less heat and fewer hours of light.

The Day

The length of the day is set by the Earth's rotation speed on its axis. One day is defined as one rotation. However, we must be careful how we measure our planet's rotation. For example, we might use the time from one sunrise to the next to define a day. That, after all, is what sets the day-night cycle around which we structure our activities. However, we would soon discover that the time from sunrise to sunrise changes steadily throughout the year as a result of the seasonal change in the number of daylight hours. A better time marker might be the time it takes the Sun to move from its highest point in the sky on one day (what we technically call apparent noon) to its highest point in the sky on the next day—a time interval that we call the **solar day.**

If we measure the length of the solar day, however, we will discover that it is, in general, *not* exactly 24 hours. Moreover, its length changes by several minutes over the course of the year. As we will discover later, this variation arises from the Earth's motion around the Sun. Thus, although the Sun's motion across the sky determines the day-night cycle, the

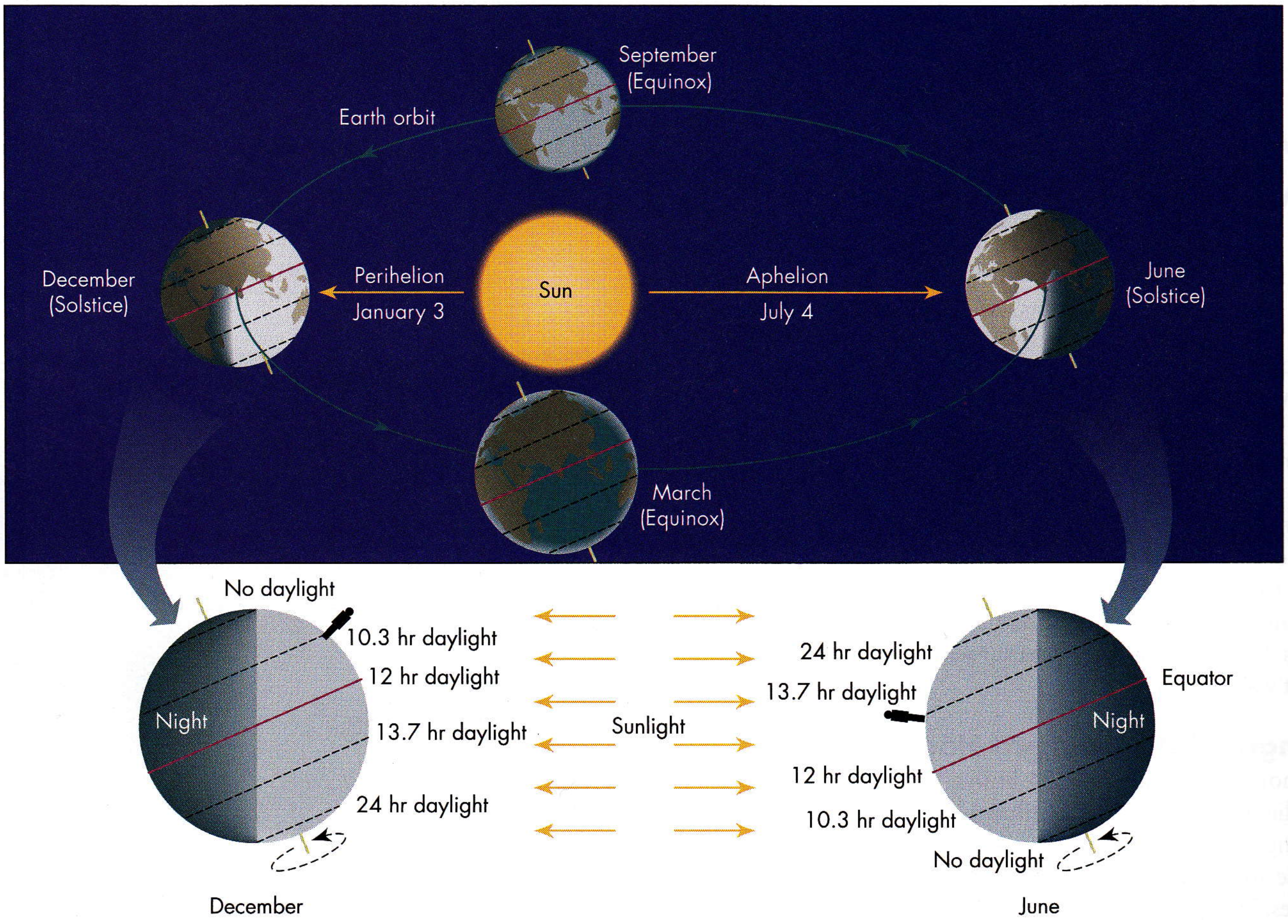


FIGURE E2.1
The tilt of the Earth affects the number of daylight hours. Locations near the equator always receive about 12 hours of daylight, but locations toward the poles have more hours of dark in winter than in summer. In fact, above latitudes 66.5°, the Sun never sets for part of the year and never rises for another part of the year (the midnight sun phenomena). At the equinoxes, all parts of the Earth receive the same number of hours of light and dark.

Sun's motion is *not* a good reference for the actual time it takes our planet to complete one spin.

We can avoid most of this variation in the day's length if, instead of using the Sun, we use a star as our reference. For example, if we pick a star that lies exactly overhead at a given moment and measure the time it takes for that same star to return to exactly overhead, we will find that the time interval is not 24 hours but an essentially unchanging 23 hours and 56 minutes. This day length, measured with respect to the stars, we call a **sidereal day.**

Why do the solar and sidereal day differ in length? We can see the reason by looking at figure E2.2, where we measure the interval between successive apparent noons—a solar day. Let us imagine that at the same time we are watching the Sun, we can also watch a star and that we measure the time interval between its passages overhead, a sidereal day.

As we wait for the Sun and star to move back overhead, the Earth moves along its orbit. The distance the Earth moves in one day is so small compared with the star's distance that we see the star in essentially the same direction as on the previous day. However, we see the Sun in a measurably different direction, as figure E2.2 shows. The Earth must therefore rotate a bit more before the Sun is again overhead. That extra rotation, needed to compensate for the Earth's orbital motion, makes the solar day slightly longer than the sidereal day.

It is easy to figure out how much longer on the average the solar day must be. Because it takes us 365¼ days to orbit the Sun and because there are by definition 360 degrees in a circle, the Earth moves approximately 1 degree per day in its orbit around the Sun. That means that for the Sun to reach its noon position, the Earth must rotate approximately 1 degree past its position at the previous noon.* In 24 hours = 24 × 60 = 1440 minutes, the Earth rotates 360 degrees. Therefore, to rotate

*Another way of thinking about this is that the Sun is slowly moving eastward across the sky through the stars at the same time the Earth is rotating. Thus, in a given "day," the Earth must rotate a bit more to keep pace with the Sun than it would to keep pace with the stars.

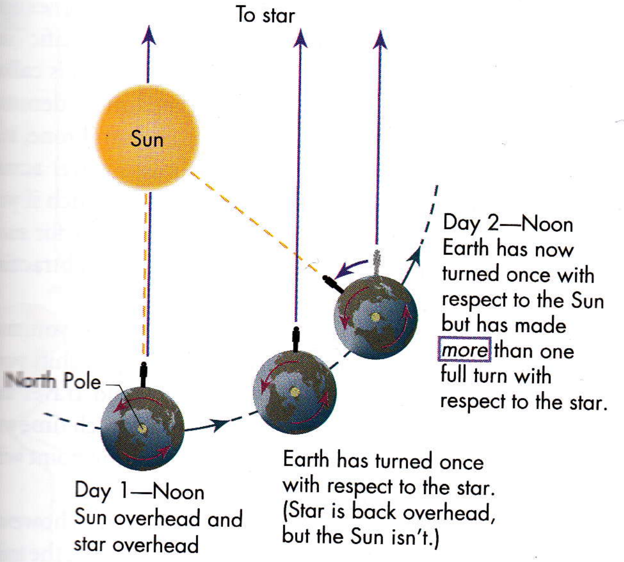


FIGURE E2.2
The length of the day measured with respect to the stars is not the same as the length measured with respect to the Sun. The Earth's orbital motion around the Sun makes it necessary for the Earth to rotate a tiny bit more before the Sun will be back overhead. (Motion is exaggerated for clarity.)

1 degree takes 1440/360 minutes, or about 4 minutes. The solar day is therefore about 4 minutes (3 minutes 56 seconds, to be precise) longer than the sidereal day.

As mentioned earlier, the motion of the Earth around the Sun alters the length of the solar day. If you measure carefully the time interval from one apparent noon to the next, in general, it is not 24 hours but may differ slightly either way. This variation arises because the Earth's orbit is not circular, and therefore, our orbital velocity changes according to Kepler's second law.

The Earth moves along its orbit faster when it is near the Sun and slower when it is farther away. This means that it takes a little longer for the Earth to swing you around into the morning Sun (slightly lengthening the interval between successive noons) when the Earth is moving rapidly in its orbit than when it is moving slowly (fig. E2.3). Hence, the solar day is longer when we are near the Sun and shorter when we are farther away. The amount by which the length of the solar day varies is small, but it must be accounted for if our clocks are to always read about noon when the Sun is highest in the sky.

We could design clocks so that the hour is of different lengths at different times of the year. That could be done to

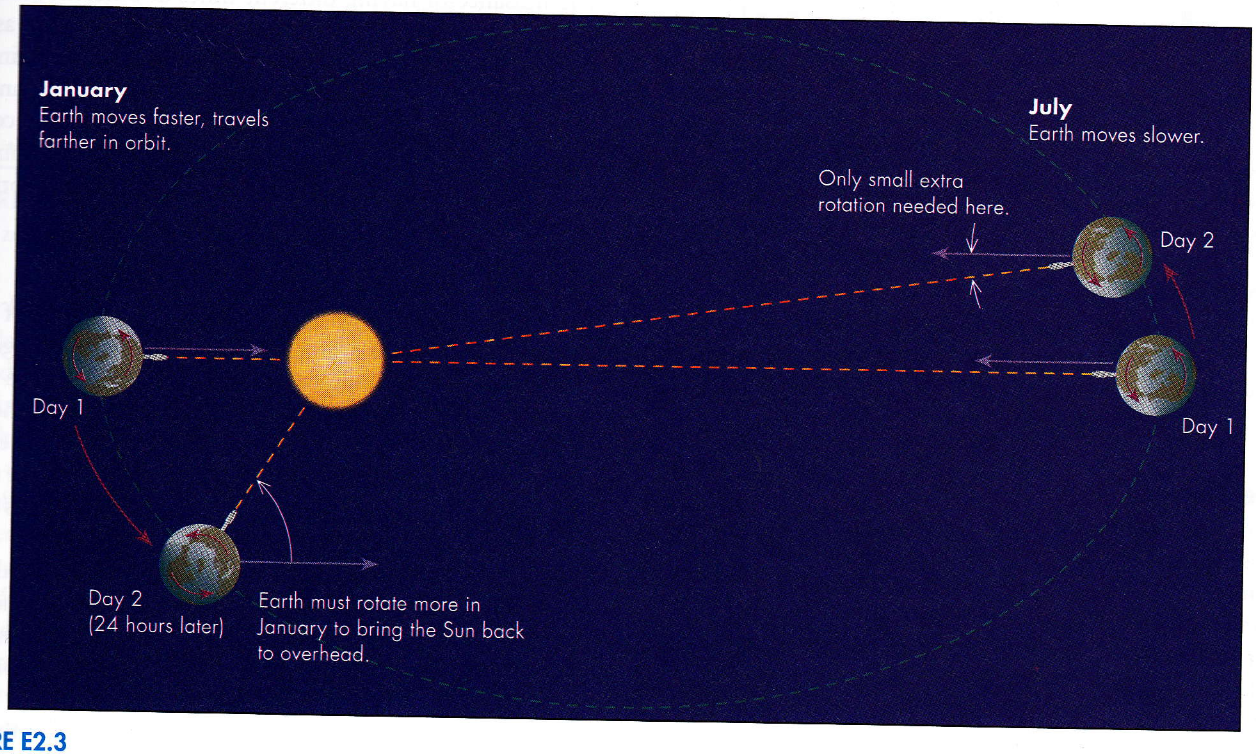


FIGURE E2.3
As the Earth moves around the Sun, its orbital speed changes as a result of Kepler's second law of motion. For example, the Earth moves faster in January when it is near the Sun than in July when it is far from the Sun. Thus, in 24 hours the Earth moves farther along its orbit in January than in July. As a result, the Earth must turn slightly more in January to bring the Sun back to overhead. This makes the interval between successive noons longer in January than in July and means they are not exactly 24 hours. For that reason, time is kept using a "mean Sun" that moves across the sky at the real Sun's average rate.

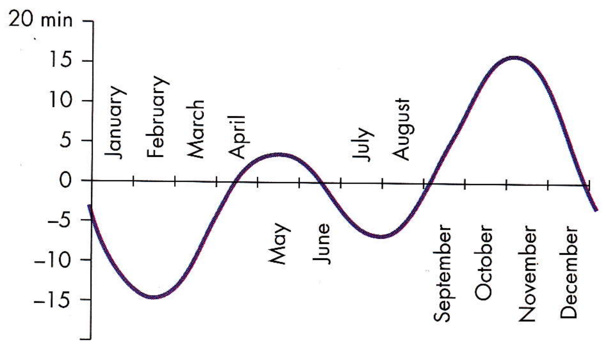


FIGURE E2.4

The equation of time is the correction that must be applied to the true Sun to determine mean solar time. It can be shown as a graph (left) or as a figure-8 shape called an "analemma."

ensure that our clocks advance to conform with the changing length of the solar day. However, it is much easier to define the length of the day differently, using not the true interval from one apparent noon to the next, but the *average* value of that interval over the year. That average daylength is called the **mean solar day,** and it has, by definition, 24 hours of clock time. We therefore use mean solar time in our daily timekeeping.

The difference in length between the mean solar day and the true solar day accumulates over time and leads to a difference of several minutes between clock time and time based on the position of the Sun. This difference is called the "equation of time" and is shown graphically in figure E2.4. The equation of time gives the correction needed on a sundial if it is to give the same time as your watch.

Although we use solar time in regulating our daily activities, astronomers find sidereal time extremely useful. One reason is that, at a given location, a given star always rises at the same sidereal time. To avoid the nuisance of A.M. and P.M., sidereal time is measured on a 24-hour basis. For example, the bright star Betelgeuse in the constellation Orion rises at about 10 P.M. in November but at about 8 P.M. in December. However, on a clock keeping sidereal time, it always rises at the same time at a given location, about 23 hours 50 minutes.

Time Zones

Because the Sun is our basic time-keeping reference, most people like to measure time so that the Sun is highest in the sky at about noon. This is unnecessary now that we have good electronic clocks that can keep time independent of the Sun. Nevertheless, it is a tradition that is hard to break, and as a result, clocks in different parts of the world are set to read different times. Because the Earth is round, the Sun can't be "overhead" everywhere at the same time, so it can't be noon everywhere at the same time.

The Earth is therefore divided into 24 major **time zones** in which the time differs by one hour from one zone to the next. There are a few exceptions, but we'll ignore them here.

Across the contiguous 48 United States, the time zones are, from east to west, Eastern, Central, Mountain, and Pacific (see fig. E2.5). The time within each zone is the same and is called **standard time.** Thus, in the eastern zone, the time is denoted Eastern Standard Time (EST), whereas in the central zone, it is denoted Central Standard Time (CST). As you travel across the country, it is therefore necessary to reset your watch if you cross from one time zone to another, adding 1 hour for each time zone as you move from west to east and subtracting 1 hour when you move from east to west.

If you travel a very large number of time zones, you may need to make such a large time correction that you shift your watch past midnight. For example, if you could travel fast enough and far enough, setting your watch back each time you cross a time zone, you could end up at your starting point with your watch set to a time 24 hours before you left!

A high-speed traveler cannot actually "gain" a day, however, because when you cross longitude 180° (roughly down the middle of the Pacific Ocean), you add a day to the calendar if you are traveling west and subtract a day if you are traveling east. The precise location where the day shifts is called the **international date line** (fig. E2.5). It generally follows 180° longitude but bends around extreme eastern Siberia and some island groups to ensure they keep the same calendar time as their neighbors.

Universal Time

The nuisance of having different times at different locations can be avoided by using **Universal time,** abbreviated as UT. Universal time is the time kept in the time zone containing the longitude zero, which passes through Greenwich, England. By using UT, which is based on a 24-hour system to avoid confusion between A.M. and P.M., two people at remote locations can decide to do something at the same time without worrying about what time zone they are in.

Daylight Saving Time

In many parts of the world, people set clocks ahead of standard time during the summer months and then back again to standard time during the winter months. This has the effect of shifting sunrise and sunset to later hours during the day, thereby creating more hours of daylight during the time most people are awake. Time kept in this fashion is therefore called **daylight saving time** in the United States. In other parts of the world, it is called "Summer Time."

Daylight saving time was originally established during World War I as a way to save energy. By setting clocks ahead, less artificial light was needed during work hours late in the day. Nowadays, it allows us more daylight hours for recreation after work during the summer.

Daylight saving time in the United States currently runs from the first weekend in April to the last weekend in October. However, many people advocate extending it a month earlier and later. This would presumably save energy by lessening still more the need for artificial light during waking hours.

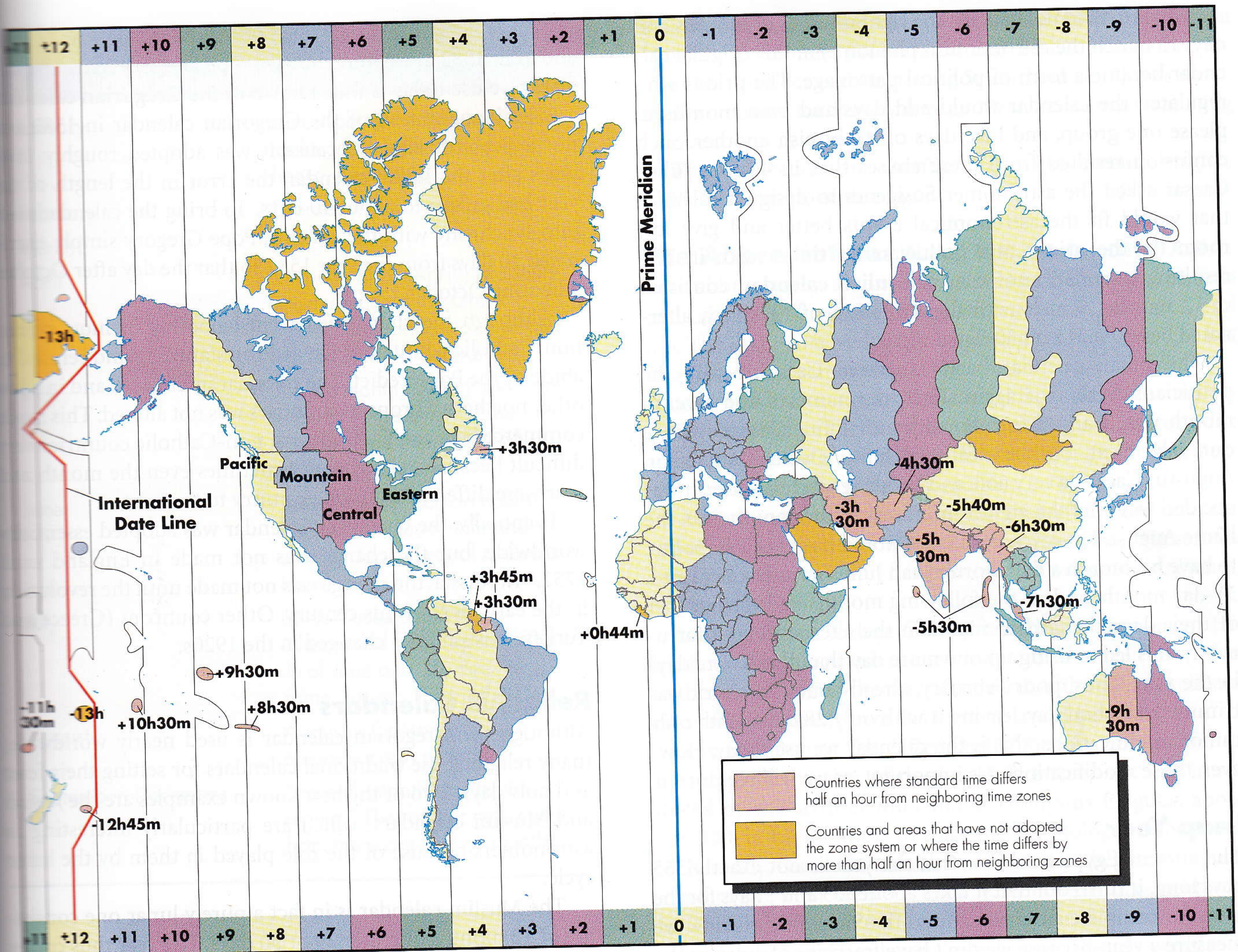


FIGURE E2.5
Time zones of the world and the international date line. Local time = Universal time − numbers on top or bottom of chart.

The Month

The day with its 24 hours is excellent for keeping track of short periods of time, but for longer intervals, longer time units are helpful. Of these other units, the month is the next largest unit used by nearly all cultures.

As you know from looking at a calendar, the month is usually about 30 days long. This time interval, and its name, derives from the Moon's cycle of phases. The time interval between full moons is about 29.5 days, which for use on the calendar is rounded off to 30. Because the year has about 365 days in it, there are about 12 lunar cycles per year. That is the reason that we have 12 months in the year.

You will notice, however, that 12 lunar cycles of 30 days ends up 5 days short of a full year. For that reason, some of the months are made 31 days long. In fact, if every other month, starting with January, were a 31-day month, the year would total 366 days. To make the days add up to 365, February is trimmed 1 day, to 29.

But, you protest, that is not the way the calendar looks. Although January, March, May, and July have 31 days, the sequence is broken in the later months. You see at work there the politics of ancient Rome.

The Calendar

Our calendar is based on one developed about 200 B.C. by the Romans. In fact, the word *calendar* is itself of Roman origin. There is some controversy about how the original Roman calendar was organized. It may have had only 10 months, and it probably began on the first day of spring (the vernal equinox) rather than in January.

Certainly the names of our months date from that calendar and its modifications. For example, if the year began in March, then September, October, November, and December were the 7th (Sept.), 8th (Oct.), 9th (Nov.), and 10th (Dec.) months, respectively.

Because it did not contain the right number of months and days to match the astronomical phenomena, this original calendar became a form of political patronage. The priests who regulated the calendar would add days and even months to please one group, and take days off to punish another. Such confusion resulted from these abuses that in 46 B.C., Julius Caesar asked the astronomer Sosigenes to design a calendar that would fit the astronomical events better and give less room for the priests and politicians to tinker with it. The resulting calendar, known as the **Julian calendar,** consisted of 12 months, which with the exception of February, alternated between 31 and 30 days in length.

The Julian calendar barely survived Caesar before the politicians were at it again. First, the name of the seventh month was changed to Julio to honor Julius Caesar—hence our July. Next, on the death of Julius Caesar's successor, Augustus Caesar, a very able and highly respected leader, it was decided to name the eighth month in *his* honor—hence, the name August. However, because it would have been impolitic to have his month a day shorter than Julius's, August became a 31-day month, and all the following months had the number of their days changed to maintain the alternation. Unfortunately, this led to using up one more day than there were days in the year. Thus, poor February, already one day short, was trimmed a second day, leaving it with only 28 days. With only minor modifications, this is the calendar we use today. However, those modifications are important, as we will see.

Leap Year

The ancient Egyptians knew that the year is not exactly 365 days long. It turns out that it takes about 365 and $\frac{1}{4}$ days for the Earth to complete an orbit around the Sun, which is how we measure a year. Because we can't have fractions of a day in the calendar, a calendar based on a year of 365 days will come up 1 day short every 4 years.

Your first reaction might be, So what? However, the seasons are set by the orientation of the Earth's rotation axis with respect to the Sun, not by how many days have elapsed. We therefore want to make sure that we start each year with the Earth having the proper orientation. Otherwise, the seasons get out of step with the calendar. For example, because in 4 years you will lose 1 day, in 120 years you will lose a month, and in 360 years, you will lose an entire season. With a 365-day year, in a little over three centuries, April would be coming in what is now January.

This problem is corrected by leap year, a device used by the ancient Romans to keep the calendar in step with the seasons. Leap year corrects by adding a day to the calendar every fourth year. The extra day is traditionally added to February because it is the shortest month.

Unfortunately, the year is actually a little bit shorter than $365\frac{1}{4}$ days. Thus, leap year corrects a tiny bit too much. To deal with this problem, centuries that are not divisible by 400 are not leap years. Thus, 1900 was not a leap year, but 2000 was. This modification of omitting leap year for all century years not divisible by 400 was not part of the Julian calendar but was added in 1582 at the direction of Pope Gregory XIII. The calendar we use today is thus known as the **Gregorian calendar.**

The inauguration of the Gregorian calendar in 1582 was not a peaceful affair. Because it was adopted roughly 1600 years after the Julian calendar, the error in the length of the year had grown to about 10 days. To bring the calendar back into synchrony with the seasons, Pope Gregory simply eliminated 10 days from the year 1582 so that the day after October 4 became October 15.

Although the changeover went smoothly in most places, non-Catholic countries such as Protestant England refused to abide by the Pope's edict. The calendar in England and in a few other northern European countries was not altered. This made commerce between Catholic and non-Catholic countries very difficult because the day and sometimes even the month and year were different from one country to the next.

Eventually, the Gregorian calendar was adopted essentially worldwide, but the change was not made in England until 1752.* In Russia, the change was not made until the revolution in the early part of this century. Other countries (Greece and Turkey, for example) changed in the 1920s.

Religious Calendars

Although the Gregorian calendar is used nearly worldwide, many religions use traditional calendars for setting their feast and holy days. Two of the best known examples are the Jewish and Muslim calendars, which are particularly interesting to astronomers because of the role played in them by the lunar cycle.

The Muslim calendar is in fact a purely lunar one consisting of 12 months of either 29 or 30 days. The year thus comes out about 11 days shorter than those in the Gregorian calendar. This means that the Muslim calendar is totally out of synchrony with the seasons. As a result, the holy month of Ramadan can fall at any time during the year, irrespective of the season. This may seem odd to people living in climates with strong seasonal variations, but for people living in the Middle East where seasons are very unremarkable, it makes little difference.

Likewise, the Jewish calendar is based on the lunar cycle. To correct for the missing days, from time to time an extra month is added in the middle of the year to keep it in step with the seasons. The Jewish calendar is especially interesting astronomically because it begins near the autumnal equinox and the extra month is added near the vernal equinox. Also, the holy days of Yom Kippur and Passover are located near the equinoxes, a feature shared by the Gregorian calendar, wherein Easter is near the vernal equinox (actually the first Sunday after the first full moon after the equinox) and Christmas is near the winter solstice.

*This elimination of some 10 days from the calendar supposedly led to riots by people fearing they would be charged a full month's rent for only 20 days.

TABLE E2.1
Origin of the Names of the Months

January	Janus (gate), the two-faced god looking to the past and future; hence, beginnings.
February	Februa, (expiatory offerings).
March	The god Mars.
April	Etruscan *apru* (April), probably shortened from the Greek Aphrodite, goddess of love and earlier of the underworld.
May	Maia's month; Maia ("she who is great"), the eldest of the Pleiades and the mother of Hermes by Zeus.
June	Junius, an old Roman noble family (from Juno, wife and sister of Jupiter, equal to Greek Hera).
July	Julius Caesar (Julius "descended from Jupiter"; The *Ju* of June and July are the same: Jupiter, "Sky-father").
August	Augustus Caesar (*augustus* means sacred, grand).
September–December	"Seventh-month" to "tenth-month." The *-ember* may come from the same root as *month*.

Other Calendars

Another calendar of note is the Chinese one, which, like the Jewish calendar, combines lunar and seasonal aspects. The Chinese calendar is based on a 365.2444-day year broken up into 6 cycles of 60 days. The years are themselves grouped into 60-year cycles composed of 5 cycles repeating every 12 years. The years in each 12-year cycle are given names such as the Year of the Rat, the Year of the Dog, and so forth. Days and months are added so that it works out to match the cycle of the seasons.

Names of the Months and Days

That there are seven days in the week is probably a result of there being seven visible objects that move across the sky with respect to the stars: the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn. We can see the names of some of these bodies in our English day names (Sunday, Monday, and Saturday). The influence is even clearer in the romance languages, such as Spanish (*lunes, martes, miércoles, jueves, viernes*).

Some English day names come to us through the names of Germanic gods (many of whom have a direct parallel with the Greco-Roman gods after whom the planets are named). For example, Tuesday is from *Tīw*, god of war, like Mars (matching Spanish *martes*). Wednesday is named for *Wōden*, the chief god of Germanic peoples and identified with the Roman Mercury (matching Spanish *miércoles*). Thursday is named for *Thōr*, the thunder god (matching Spanish *jueves*, 'Jove's day'). Friday is named for *Freya*, a love goddess, like Venus (matching *viernes*).

The names of the months have less certain origins. Table E2.1 lists possible origins.

The Abbreviations A.M., P.M., B.C., and A.D.

Four abbreviations are used frequently in the measure of time and calendars. They are the familiar letters A.M., P.M., B.C., and A.D. The first two have specific astronomical meaning. The last two have cultural meaning.

A.M. and P.M. stand for "ante meridian" and "post meridian," respectively. The meridian is the line passing from due north to due south and passing directly through the point exactly overhead (also called the zenith).

As the Sun moves across the sky, it crosses the meridian at the time called apparent noon. Before noon, it lies before (ante) the meridian. After noon, it lies past (post) the meridian. Hence, A.M. and P.M.

B.C. stands for "before Christ," referring to the year of His birth. Oddly, there is no convention as to whether 1 B.C. refers to the year before or the year of his birth, although most historians make it the year of his birth to avoid having a year "0."

A.D. stands, not for "after death," but for *anno Domini*, meaning "in the year of the Lord." The term A.D. was introduced by the sixth-century monk Dionysius Exiguus, about A.D. 528, in his attempts to trace the chronology of the Bible.

Recently, two different abbreviations have begun to replace A.D. and B.C. They are B.C.E. and C.E., which stand, respectively, for "before common era" and "common era." "Common era" refers to our present calendar, which is used nearly worldwide for most business purposes and thereby avoids reference to a particular religion. Yet another abbreviation—B.P.—is used, especially in anthropological and geological works. B.P. stands for "before present (era)" and is used for dates determined by analyzing the radioactive carbon in the object of interest. It takes 1950 C.E. as its base year.

Summary

Our system for keeping time is based on the motion of the Earth, Moon, and Sun. The day is determined by the Earth's spin, the month by the Moon's orbital motion around the Earth, and the year by the Earth's orbital motion around the Sun.

The solar day is based on the time interval between one apparent noon and the next. The sidereal day, or the interval between the time of star-rise for a given star and the time of its next rising, is about 4 minutes shorter than the solar day. This difference arises because, as the Earth moves along its orbit, the direction to the Sun shifts slightly. We must therefore wait a little longer to allow the Earth's rotation to carry us into the same position with respect to the Sun.

Time zones divide the Earth into regions such that the time differs by 1 hour (in general) from zone to zone. The resulting

time difference allows the Sun to be approximately at its highest point above the horizon at noon in each zone.

The Earth makes approximately 365.25 rotations in the time it takes it to complete one orbit around the Sun. Thus, every 4 years, an extra day accumulates, which in leap years we add to the calendar as February 29.

Questions for Review

1. How is the solar day defined? How is the sidereal day defined?
2. Why do the sidereal and solar days differ in length?
3. Why do we need a leap year?
4. Why isn't the solar day always exactly 24 hours long?
5. What do A.M., P.M., A.D., and B.C. stand for?
6. Suppose you were asked to revise the calendar. What changes would you make?

Test Yourself

1. Suppose that the length of the year was 365.2 days instead of 365.25 days. How often would we have leap year? Every
   (a) 2 years.
   (b) 5 years.
   (c) 10 years.
   (d) 20 years.
   (e) 50 years.
2. Suppose the Earth's rotation axis was not tilted with respect to its orbit. How would the number of daylight hours change throughout the year?
   (a) The number would be no different.
   (b) Days would be longer and nights shorter at all times of the year.
   (c) Days and nights would be of equal length throughout the year.
   (d) Days would be shorter and nights longer throughout the year.
   (e) None of the above
3. Why is February the shortest month?
   (a) The Earth is moving most slowly in its orbit then.
   (b) The Earth is moving fastest in its orbit then.
   (c) The Earth spins faster in February than at other times of the year.
   (d) The Earth spins slower in February than at other times of the year.
   (e) When the calendar was revised, days were taken from February to make other months longer.
4. If on a given date the night is 24 hours long at the North Pole, how many hours long is the night at the South Pole?
   (a) 24 hours
   (b) 12 hours
   (c) 36 hours
   (d) 48 hours
   (e) There is no night then.
5. On what day(s) of the year are nights longest at the equator?
   (a) They are the same length throughout the year there.
   (b) The solstices
   (c) The equinoxes
   (d) Approximately June 21
   (e) Approximately December 21

Further Explorations

Bartky, Ian R., and Elizabeth Harrison. "Standard and Daylight-Saving Time." *Scientific American* 240 (May 1979): 46.

Cleere, G. S. "Eleven Lost Days." *Natural History* 100 (September 1991): 78.

Daniel, Glyn. "Megalithic Monuments." *Scientific American* 263 (July 1990): 78.

Duncan, David E. *Calendar: Humanity's Epic Struggle to Determine a True and Accurate Year.* New York: Avon Press, 1998.

Jespersen, James, and Jane Fitz-Randolph. *From Sundials to Atomic Clocks: Understanding Time and Frequency.* National Bureau of Standards Monograph 155. Washington, D.C.: U.S. Government Printing Office, 1977.

Monson, B. "A Simple Method of Measuring the Length of the Sidereal Day." *Physics Teacher* 30 (December 1992): 558.

Moyer, Gordon. "The Gregorian Calendar." *Scientific American* 246 (May 1982): 144.

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